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Study on acceleration response spectra for seismic design based on observed records in Hokkaido, JAPAN

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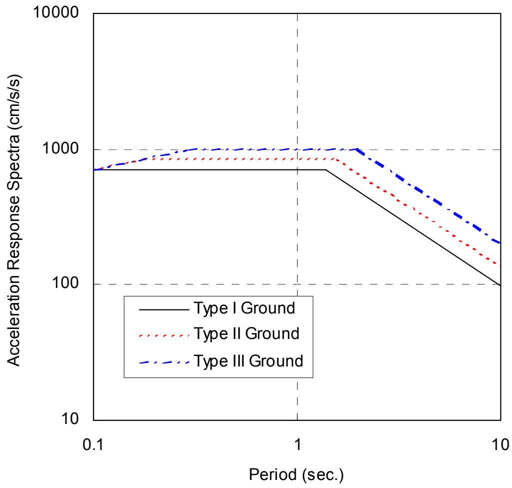
ABSTRACT :
In Hokkaido and around that, many earthquakes occurred. Just within the past 15 years, a number of earthquakes with a Magnitude of 7 or higher have occurred, such as the 1993 Kushiro-oki Earthquake (M7.5), the 1993 Hokkaido Nansei-oki Earthquake (M7.8), the 1994 Hokkaido Touhou-oki Earthquake (M8.2), the 2003 Tokachi-oki Earthquake (M8.0), and the 2004 Kushiro-oki Earthquake (M7.1). To reduce the damage from those earthquakes, it is important to understand the features of their ground motions. Valuable ground motion records which reflect the area's unique characteristics have been obtained, since earthquake observation in Hokkaido began in 1966. And in 1996, many earthquake observation records were archived by the National Research Institute for Earth Science and Disaster Prevention (NIED) earthquake observation network. So, with the goal of creating the best seismic design methods for national highway bridges in Hokkaido, the acceleration response spectra in the seismic designs in these observation records were studied.

KEYWORDS:
seismic design, strong ground motion, acceleration response spectra

1. INTRODUCTION

In Japan, there are a specific set of seismic design standards that are followed. For highway bridges, most follow Section V: Seismic design of the Highway Design Standards[1)]. These Standards were established in 1980 using the most recent research available. They were revised in 1990, 1996, and 2000. In the 1996 revision, the seismic designs were heavily changed with regard to ground motions in light of the substantial damage from the 1995 Hyogo Nanbu Earthquake. Specifically, earthquakes were separated into two types: those which were interplate earthquake (Type 1) and those which were inland earthquakes (Type 2). Compared with the extremely large ground motions created by inland earthquakes which hit directly above their epicenters, seismic resistance could be guaranteed even against earthquakes at a Magnitude of 7. The 2000 revision defined the two grades of ground motion intensity introduced in the 1996 revision (Level 1 and Level 2), making the path of seismic design even more clear. Level 1 ground motions are those that are very likely to occur on bridges during an earthquake, and Level 2 ground motions are those which are not likely to occur on bridges during earthquakes, but have high intensity.

According to these Standards, there are two possible methods for generating the earthquake's external force in seismic designs, and one of them is the regulations for acceleration response spectra. In these methods, the acceleration response spectra are dependent upon the earthquake and ground types, and are created using seismic designs that multiply the coefficients of the unique characteristics of the structure with the unique characteristics of the area. The acceleration response spectra for Level 2 ground motions are rather large, able to deal with even large-magnitude earthquakes, by considering the ground motions from past earthquakes. For a region where seismic risk is low, seismic force is reduced by multiplying the above mentioned local correction factor. Its minimum value is 0.7. Even for a region where seismic risk is extremely low, it is necessary to conduct aseismic design while assuming external seismic force that is equal to 0.7 × the value in a region where seismic risk is high, and external seismic force may be overestimated according to conditions.



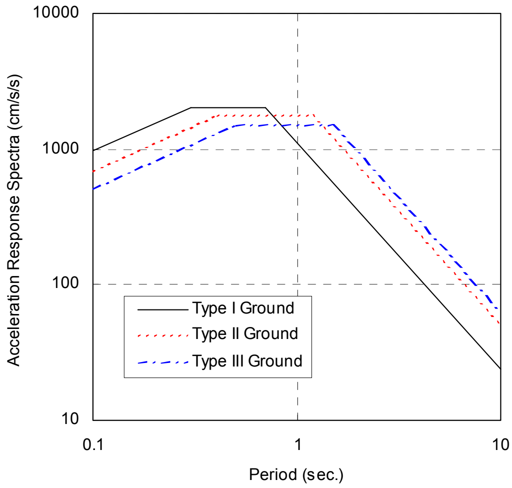


Figure 1. Standard acceleration response spectra for seismic design

Table 1 Ground type in seismic design

Ground Type	Characteristics value of ground (s)
Type 1	$T_G < 0.2$
Type 2	$0.2 =< T_G <0.6$
Type 3	$0.6 =< T_G$

In this circumstance, we discussed acceleration response spectra, which are obtained from earthquake observation records and used for seismic design, with the purpose of developing a seismic design method. The study target is Hokkaido, where seismic risk is outstandingly high in Japan. Since there is a well-established network for earthquake observation, which have plentiful records on relatively large-scale earthquakes, Hokkaido is the best target place for this study.

2. Standard response spectra on Specifications for Highway Bridges

Acceleration response spectra were generated in compliance with ground type and the two types of earthquakes in the Specifications for Highway Bridges (plate boundary earthquakes [Type 1] and inland earthquake [Type 2]). Acceleration response spectra were generated according to Formula (1). The decay constant for the acceleration response spectra calculations was 5%.

Figure 1 shows standard acceleration response spectra for Type I and Type II. The ground type was calculated using the ground's unique characteristic values in Formula (2), and the results are shown in Table 1. Type I earthquakes were thought to break out along sunken bands along the Pacific coast of the Japanese islands, as the ground motions in the 1923 Kanto Earthquake were. Some were distant from the epicenter with a large epicenter range, and the seismic amplitude in the long period areas was taken into consideration. In Type II earthquakes along inland active faults, it was thought that there would be ground motions with extremely high amplitudes, as in the 1995 Hyogo Nanbu Earthquake. Therefore, comparatively short period areas would have large amplitudes.

The acceleration response spectra used in seismic design is calculated, as mentioned above, by multiplying the coefficient of the standard acceleration response spectra with the area coefficient (the area difference correction coefficient). Figure 2 shows the area difference correction coefficient. Areas with an extremely high earthquake susceptibility (Zone A) had an area difference correction coefficient of 1.0, while areas with an extremely low earthquake susceptibility (Zone C) had an area difference correction coefficient of 0.70. Zone B came between them with a coefficient of 0.85. So that the structurally-dependent coefficient would not be influenced by the earthquake susceptibility, this study focused on the acceleration response spectra calculated by the multiplication of the standard acceleration response spectra by the area difference correction coefficient.

When ground motions that conformed to the generated acceleration response spectra were produced, they were used as an input to verify the structure's seismic resistance.

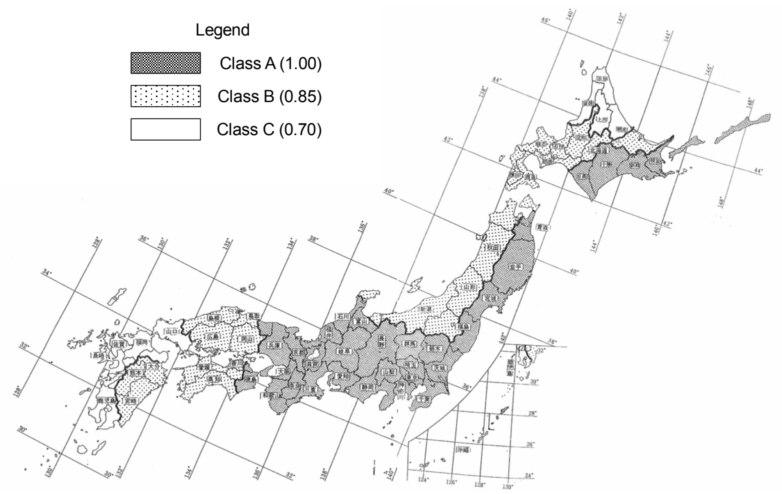
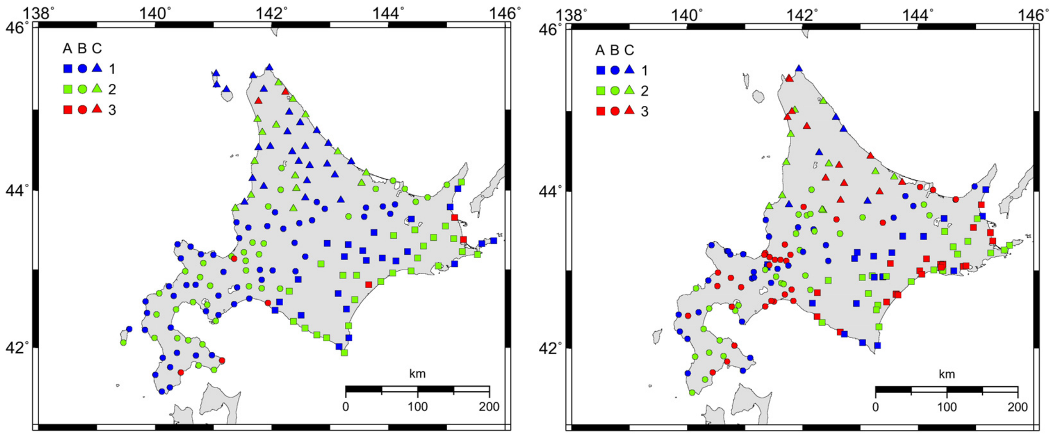


Figure 2. Regional classification and modification factor



(a)WISE (b)K-NET

Figure 3. Location of seismic station in Hokkaido, Japan

$$T_G = 4\sum_{i=1}^{n}\frac{H_i}{Vs_i} \qquad (1)$$

T_G: Characteristics value of ground (s)
H_i: Thickness of the i-th soil layer(m)
Vs_i: Average shear elastic wave velocity of the i-th soil layer (m/s)
i: Number of the i-th soil layer from the ground surface when the ground is classified into n layers from the ground surface to the surface of a base ground surface for seismic design

$$S = c_z c_D S_0 \qquad (2)$$

S Acceleration Response Spectra (h=0.05)
c_z Modification factor for zones specified
c_D Modification factor for damping ratio
S_0 Standard acceleration response spectra

3. Strong ground motion record

Data for this study was provided by several earthquake observation networks such as WISE, of the Hokkaido Development Bureau[2)], the Disaster Prevention Research Institutes K-NET[3)] and KiK-net[4)], and the

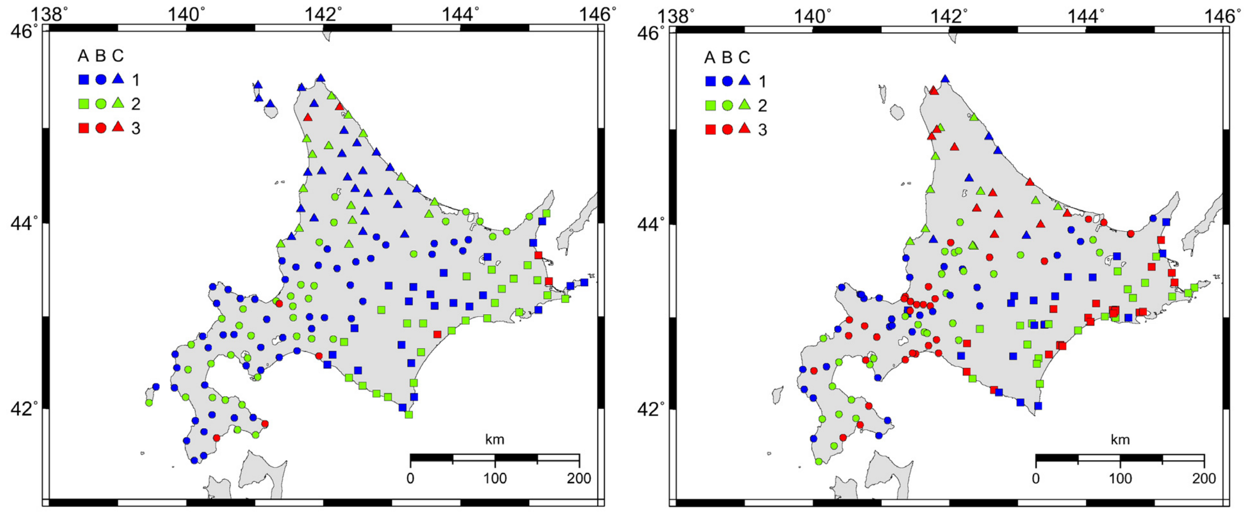


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Figure 3. Location of seismic station in Hokkaido, Japan

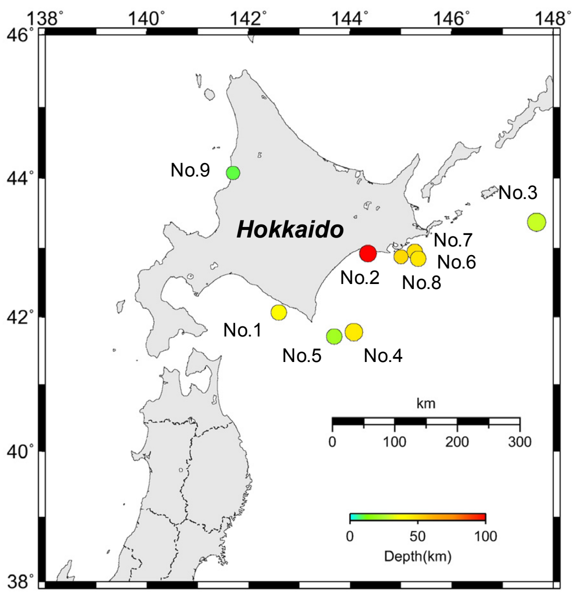


Figure 4. The location of epicenter where the JMA scale seismic intensity was greater than 5

Meteorological Agency[5]. Because, for this study, acceleration response spectra needed to be generated for each ground classification, ground motion records from WISE and K-NET were used.

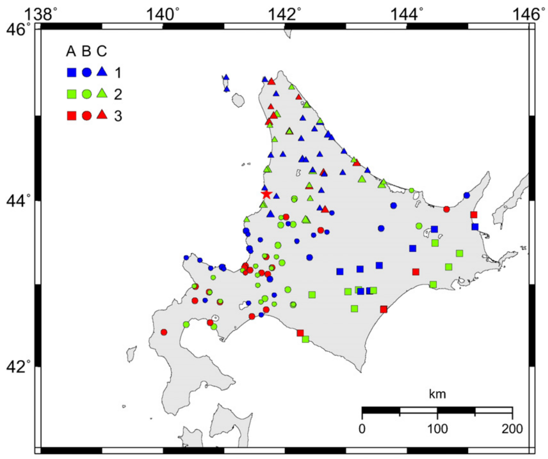
WISE has been the earthquake observation network for the Hokkaido area since 1966. From 1994 to the present, they have placed seismographs in 197 locations. K-NET is a severe earthquake observation network for all of Japan, with locations at around 25 km intervals throughout the country, and has been in operation since 1996. The observation records are accessible to the general public via the Web. Figure 3 shows WISE and K-NET earthquake observation sites in Hokkaido. K-NET only has three types of ground in its observation sites, but WISE has covered the rest of the area.

Hokkaido has high earthquake susceptibility even for Japan, and has been host to several earthquakes over the years. According to the Meteorological Agency's Shindo earthquake scale, Hokkaido has had nine earthquakes with a magnitude of 5 or more since 1926[6]. Figure 4 shows the epicenters of the observed earthquakes with a Shindo rating of more than 5. Table 2 shows the various factors of the earthquakes. This study focused on the September 26, 2003 Tokachi-oki Earthquake (Mj8.0) and the December 14, 2004 Rumoishi-cho Nanbu Earthquake (Mj6.1).

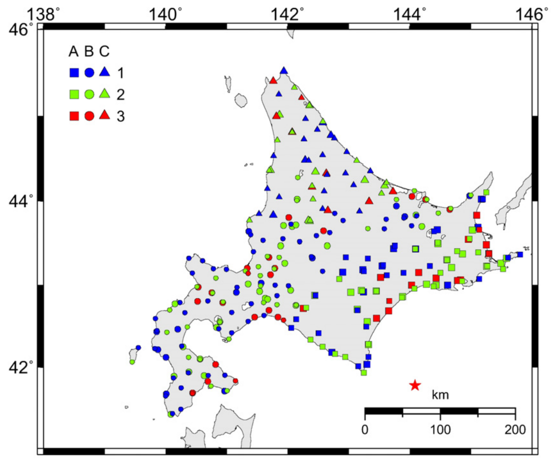
Table 2 Details of the earthquakes which is shown in Figure-4

No	Name	Type	Date Time	Mj	Epicenter	Depth	SIS_{JMA}
1	Urakawa Oki	Urakawa Type	1982/03/21 11:32:05.7	7.1	42°04.0'N. 142°36.0'E	40	6
2	Kushiro Oki	Intra plate	1993/01/15 20:06:07.2	7.5	42°55.2'N. 144°21.2'E	101	6
3	Hokkaido Toho Oki	Intra plate	1994/10/04 22:22:56.9	8.2	43°22.5'N. 147°40.4'E	28	6
4	Tokachi Oki	Inter plate	2003/09/26 04:50:07.4	8.0	41°46.7'N. 144°04.7'E	45	6-
5	Tokachi Oki	Inter plate	2003/09/26 06:08:01.8	7.1	41°42.5'N. 143°41.4'E	21	6-
6	Kushiro Oki	Inter plate	2004/11/29 03:32:14.5	7.1	42°56.7'N. 145°16.5'E	48	5+
7	Kushiro Oki	Inter plate	2004/12/06 23:15:11.8	6.9	42°50.8'N. 145°20.5'E	46	5+
8	Rumoi Shicho Nambu	Inland	2004/12/14 14:56:10.5	6.1	44°04.6'N. 141°41.9'E	9	5+
9	Kushiro Oki	Inter plate	2005/01/18 23:09:06.6	6.4	42°52.5'N. 145°00.4'E	50	5+

SIS_{JMA} : JMA Seismic Intensity Scale



(a)WISE



(b)K-NET

Figure 5. Location of seismic station which were able to observe strong ground motion

The Tokachi-oki Earthquake was classified as a plate boundary earthquake (Type I). The Rumoishi-cho Nanbu Earthquake was classified as an inland earthquake whose epicenter hit above the ground (Type II). Figure 5 shows the ground motions in the observed sites for the two earthquakes.

4. Evaluation of acceleration response spectra for seismic design

4.1 Zone A

Figure 6(a) shows the acceleration response spectra for Type I. The records for the 2003 Tokachi-oki Earthquake are shown in blue, and those for the Rumioshi-cho Nanbu Earthquake are shown in red. Every spectra encased in a thick line has been generated. The slightly thinner lines show the standard acceleration response spectra from the Specifications for Highway Bridges. The blue lines are Type I, and the red lines are Type II.
The observed acceleration response spectra show a large amplitude in areas with a short period of less than 1 second. The spectral forms were closer in Type II inland earthquakes which hit directly above the epicenter than

in Type I plate boundary earthquakes according to the 2003 Tokachi-oki Earthquake records. For the Type I spectral forms, it is assumed that the ground motions in the Kanto area during the 1923 Kanto Earthquake were relative to the distance from the epicenter. The results showed that, even for plate boundary earthquakes, ground motions in short-period areas had sizeable force if they were close enough to the epicenter. Because the epicenter of the 2004 Rumioshi-cho Nanbu Earthquake was relatively far from Zone A, its influence on the spectrum cannot be detected.

Figure 6(b) shows the acceleration response spectra for Type II. Since the spectrum for K-NET observation site HKD100 was large, all generated spectra around it exceeded the regulated spectra from the Specifications for Highway Bridges. Except for areas with comparatively long periods from Type I, the observed spectra in most period bands exceeded those of the Specifications for Highway Bridges.

Figure 6(c) shows the acceleration response spectra for Type III. The spectra's greatest amplitude was at the same level as those for Type II for the Specifications for Highway Bridges, but was a bit larger than those in Type I.

As visible from each figure in Figure 6, the spectra generated from the earthquake observation records must be generated larger than the standard acceleration response spectra from the Specifications for Highway Bridges. Also, 2003 Tokachi-oki Earthquake was a plate boundary earthquake, but the acceleration response spectral forms were close to those in Type II earthquakes which hit directly above the epicenter, and the Type I spectral forms, even assuming a large distance from the earthquake, were generated with a comparatively large amplitude and long period area, but since the amplitude in the comparatively short periods decreased in the observed ground motions, the long period bands were overestimated.

4.2 Zone B

Figure 7(a) shows the acceleration response spectra for Type I ground once more. The lines with medium thickness take into account Zone B's area difference correction coefficient (=0.85). Unlike in Zone A, except for a small portion of the period, the range of acceleration response spectra fit within the Specifications for Highway Bridges. Figures 7(b) and (c) show the Type II ground and Type III ground response spectra once more. Just as in the Type I ground, the acceleration response spectra that envelops almost everything, except for one portion of the period band, were at the same level as the Type I acceleration response spectra in the Specifications for Highway Bridges.

4.3 Zone C

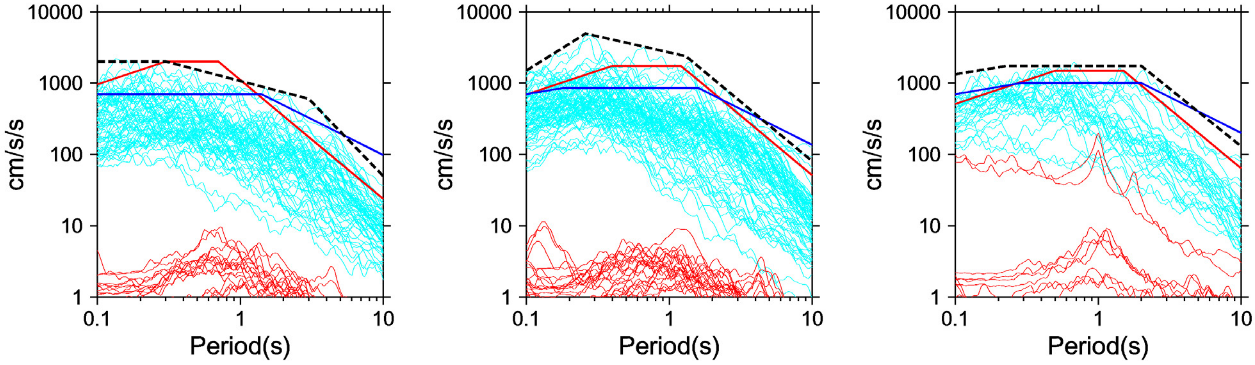
Figure 8(a) shows the acceleration response spectra for Type I ground once again. Because this is the area where the epicenter of the 2004 Rumioshi-cho Nanbu Earthquake was located, the large amplitude of the acceleration response spectra can be observed. Except for an area of quite short period, the spectra are the same level as in Type I.

On the one hand, because the spectra for the 2003 Tokachi-oki Earthquake were far from the epicenter, they fell far beneath the Specifications for Highway Bridges spectra. On the other hand, if only the 2003 Tokachi-oki plate boundary earthquake is focused on, the spectra in the observation records are extremely small, and especially in short period areas of less than 1.0 seconds, the amplitude of the spectra is less than 1/5 than the Specifications for Highway Bridges.

Figure 8(b) shows the acceleration response spectra for Type II ground once again. As in the Type I ground, a large amplitude is visible in the acceleration response spectra for short-period areas for the 2004 Rumioshi-cho Nanbu Earthquake. However, they do not exceed the spectra for Type II in the Specifications for Highway Bridges. The spectra for the 2003 Tokachi-oki Earthquake were just as small as those for the Type I ground, and the enveloping generated spectra were 1/2 the size of the Specifications for Highway Bridges' Type I spectra.

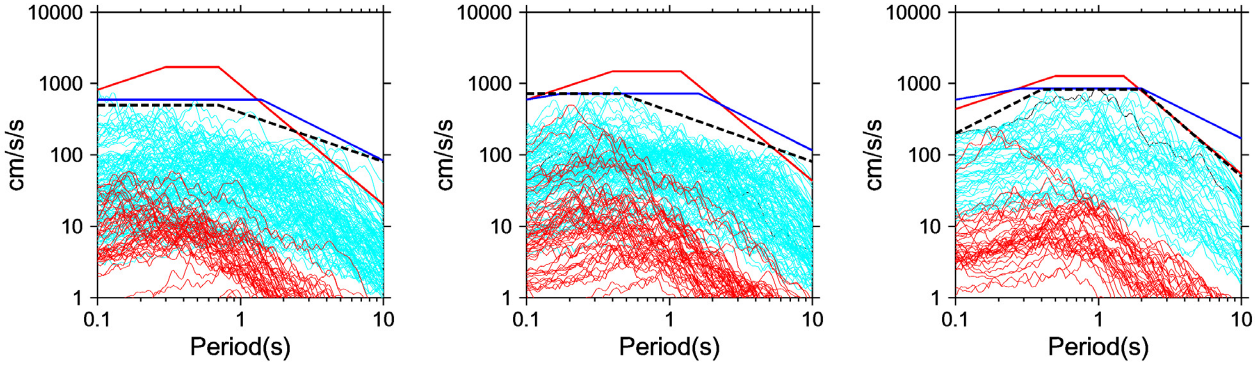
Figure 8(c) shows the Type II ground acceleration response spectra once again. The enveloping generated response spectra were 1/3 smaller than those in the Specifications for Highway Bridges.

As seen in each figure from Figure 8, the influence of the 2004 Rumioshi-cho Nanbu Earthquake on Zone C was great, and differed according to ground type. At first glance, it seems that the influence of the surface ground's degree of amplification was according to ground type, but as visible in Figure 4(f), there existed Type I ground observation sites near the epicenter, but Type III ground observation sites were all far from the epicenter. This is thought to be the reason. Therefore, it is necessary to treat plate boundary earthquakes of a generally limited scope and inland earthquakes which hit directly above the epicenter (and more difficult to limit) differently. So,



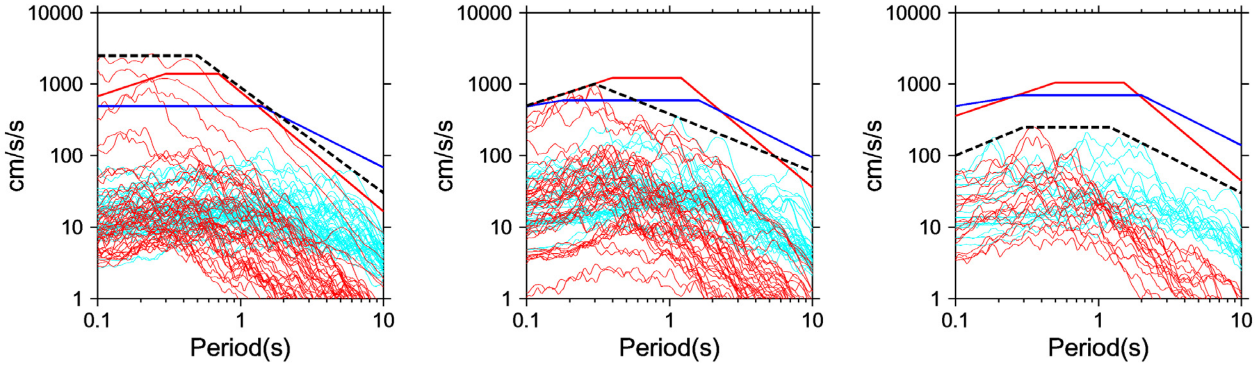
(a) Type I Ground (b) Type II Ground (c) Type III Ground

Figure 6 Acceleration response spectra in Zone A



(a) Type I Ground (b) Type II Ground (c) Type III Ground

Figure 7 Acceleration response spectra in Zone B



(a) Type I Ground (b) Type II Ground (c) Type III Ground

Figure 8 Acceleration response spectra in Zone C

it is believed that the Zones should be applied only to plate boundary earthquakes and not to inland earthquakes which hit directly above the epicenter, and this way spectra which satisfy the earthquake's scale can be generated.

5. Conclusion

This study was carried out with a goal of aiding seismic design methods by studying acceleration response spectra used in seismic designs, using ground motions observed in Hokkaido.

1. Plate boundary earthquakes had different acceleration response spectral forms from inland earthquakes which hit directly above the epicenter, but plate boundary earthquakes which were close to the epicenter had more similar spectral forms to inland earthquakes which hit directly above the epicenter.
2. In the most earthquake-susceptible areas in Hokkaido (Zone A), the acceleration response spectra partially exceeded the Specifications for Highway Bridges. On the other hand, in areas with extremely low earthquake susceptibility (Zone C), spectra that fell drastically below the regulated acceleration response spectra in the Specifications for Highway Bridges were able to be generated. And Zone B had spectra at the same level as the regulated acceleration response spectra in the Specifications for Highway Bridges.

By considering the unique area characteristics, structures constructed in these areas will be able to have the extremely important seismic designs they need. However, as seen in the acceleration response spectra for Zone A, which fell drastically below standards, it was found that dividing the area into smaller pieces is necessary.

Acknowledgements

This study used both observation records and ground conditions from the Disaster Prevention Research Institute's severe observation network K-NET. We offer our sincere thanks.

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